World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Single-family historic brick masonry house (Casa unifamiliare in centro storico, Centro Italia)

Report #	29
Report Date	06-05-2002
Country	ITALY
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Adobe / Earthen House : Mud walls
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Summary

This single-family housing type, found throughout the Central Italy (Centro Italia) mainly in hill towns and small cities, is typically built on sloped terrain. A typical house is 3 stories high, built between two adjacent buildings with which it shares common walls. The main facade of

the house faces a narrow road. The ground floor level (perforated with openings on one side only) is used for storage, while the other two stories are used for residential purposes. Typical buildings of this type are approximately 3 m wide and 9 m long. The building height on the front side is on the order of 4.5 m, whereas the height on the rear side is larger (close to 5 m). All the walls are made of unreinforced brick masonry in lime mortar, while the floor structures are vaults at the ground floor level, and timber floor structures at the higher levels. The roof is made of timber and is double-pitched, sloping down towards the front and rear walls. Buildings of this type are expected to demonstrate rather good seismic performance, mostly due to their modest height. Problems related to seismic performance might be caused by the adjacent buildings (typically one story higher). Seismic strengthening techniques for buildings of this type are well established and strengthening of some buildings has been done after the recent earthquake.

1. General Information

Buildings of this construction type can be found in Centro Italia, Marche, Emilia Romagna, and (with some modifications) in other parts of Italy as well. The specific example discussed in this contribution and the photographic and seismic documentation refer to the small town of Offida, in the Marche region. This type of housing construction is commonly found in urban areas.

This construction type is found most frequently in medieval hill towns.

This construction type has been in practice for less than 200 years.

Currently, this type of construction is being built. Traditional construction practice followed in the last 200 years with updates and modifications during the last 100 years.

Figure 1: Typical Building

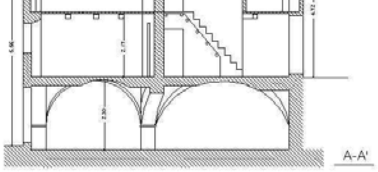


Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in sloped and hilly terrain. They share common walls with adjacent buildings.

2.2 Building Configuration

Rectangular plan, usually part of arrays or terraces, however alterations and joining of cadastral units may occur. In such case, rectangular shape still remains the most common shape. The most common "alteration" to the typical housing plan is joining of the two adjacent cadastral units. Opening layout is frequently being modified over time, due to the changes in the living requirements. A very common change is made to the ground floor entrance door which is widened in order to allow for car passage. The openings account for approximately 25% - 30% of the wall surface area. There are no openings in the side walls.

2.3 Functional Planning

The main function of this building typology is single-family house. The ground floor is originally used as storage room. At present it is used also mixed use as garage or for commercial use. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually there is not additional door besides the main entry in this building type.

2.4 Modification to Building

Alteration of door and window openings is most typical pattern of modification observed.

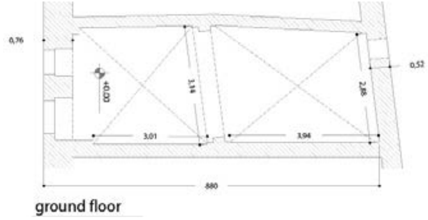


Figure 3: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☑
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐

		11	Clay brick/tile masonry, with wooden posts and beams	☐
	Confined masonry	12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

The building is of type 7, except that lime mortar has been used instead of mud mortar.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is confined masonry wall system. Depending on the thickness, the walls are built either entirely in brick masonry or, in the case of walls of larger thickness, as multi-wythe walls with rubble infill in the middle portion.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is confined masonry wall system. Brick masonry walls with or without metal ties. Typical brick dimensions are : 160 X 60 X 320 mm. In the case of very old masonry the depth of brick units can reach 80 mm. The lime mortar joints are 3-5 mm thick.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 3 and 3 meters, and widths between 3 and 3 meters. The building has 2 to 3 storey(s). The typical span of the roofing/flooring system is 3 meters. Typical Plan Dimensions: Length varies from 3 - 4 m and the width varies from 8 - 9 m. Typical Story Height: Story height varies from 2.5 to 3 m. Typical Span: Span varies from 3 - 4 m. The typical storey height in such buildings is 3 meters. The typical structural wall density is none. 0.10 to 0.20.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☑	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☑	☑
	Thatched roof supported on wood purlins	☐	☐
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☐
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐
	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Shallow Foundations Brickwork Foundations.


Figure 4A: Critical Structural Details - Brick Walls and Sloping Timber Roof


Figure 4B: Brick Walls Supporting the Cross-Vault System


Figure 4C: Cross-Section of a Typical Brick Masonry Wall

Figure 5A: Key Seismic Deficiencies-Proximity of Windows to the Corners and Vertical Extension of the Buiding (note also added balconies)

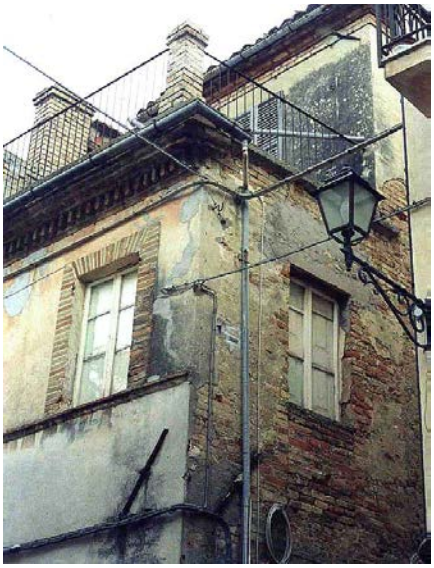


Figure 5B: Sesimic-Reslient Features - Metal Ties in two Orthogonal Direction and Brickwork Frame Around Windows

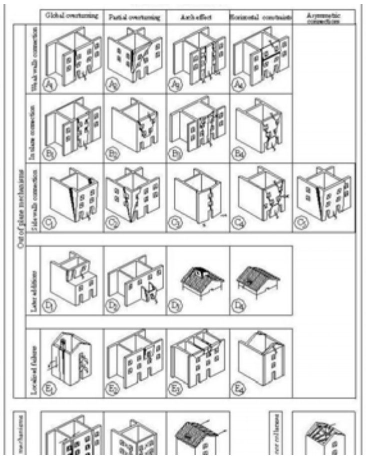


Figure 5C: Seismic Deficiencies - Failure Mechanisms

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is less than 5. In case when a house consists of only one cadastral unit, it can provide shelter for very few people. In the case of two adjacent cadastral units joined together, a larger number of inhabitants (5-7, a typical family) can be accommodated.

4.2 Patterns of Occupancy

One family per house.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☐
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

The house price can vary considerably, depending on the state of conservation and the level of modern comfort introduced. The houses of this type are usually inhabited by retirees with modest income. Some houses of this type are used as holiday homes (mainly by relatives living in other parts of the country). Economic Level: For Poor Class the ratio of Housing Unit Price to their Annual Income is 5:1. For Middle Class the ratio of Housing Unit Price to their Annual Income is 4:1.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☑
4:1	☐
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☐
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☑
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

Originally, there has been 1 latrine per housing unit, however there is often a newly fitted bathroom in recently renovated buildings. .

4.4 Ownership

The type of ownership or occupancy is renting and outright ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☐
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☑	☐	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its			

Roof construction	integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☑	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☐	☑
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	The perimeter walls are not sufficiently connected at the corners, and they behave as separate elements. This seismic deficiency is common for the buildings that were built later than the adjacent buildings. In this case, the side walls of the existing adjacent buildings were used to support the roof and floor structures of the new buildings, whereas the front and rear walls were built separately, without any connection to the existing side walls.	Presence of ties between the front walls and party walls. In some cases, metal ties perpendicular to the front wall are inserted for improving the wall connections and the global seismic performance of the building.	- Damage to the vertical addition of the building due to the out-of-plane wall failure. - - Vertical cracks associated with horizontal arch effects.

Interior Partitions	This building type is usually characterized with only one interior partition wall, running orthogonal to the front wall. This partition wall was used to support a narrow staircase joining the ground floor with the upper floors. This partition is also used to support the floor structure of the floor above it. Due to a rather moderate thickness of 150 mm, this partition wall is usually a slender wall and it represents a seismic deficiency for this building type.	In some cases, there is one interior spine wall parallel to the front wall spanning throughout the building height from the ground to the roof level. If present this wall has a role to reduce unsupported span lengths for the floor structures and provide a better support for the roof structure.	Collapse of internal timber staircase replaced by self-supported concrete staircase.
Roof and floors	Roof and floors are both spanning between the front and the rear wall. In some cases, no ties or other wall-floor connections are present. This results in a weak connection between the front/rear walls and the side walls.	Occasionally floor and roof joists are anchored to the wall by ties.	Partial or total collapse of timber floors later replaced by concrete structures.

Seismic features characteristic for the buildings of this type are shown in Figures 5A and 5B. Seismic failure mechanisms are presented in Figure 5C.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☐	☑	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1943	Castorano (AP)		VIII - IX (MMI)

The most common earthquake damage was the collapse of interior floors. The original timber floors were replaced by concrete floors in the recent past and these concrete floors caused the damage. At present there are very few original timber floors; concrete floors are much more common. It was observed that the strengthening with concrete structures tends to substantially alter the stiffness ratio of wall-to-floor structures and if not implemented properly can cause serious damage to load-bearing walls. Also, earthquake damage in buildings of this type often occurs in the vertical addition to the building (a portion of more recent construction). Earthquake damage patterns include the flexural wall failure and the horizontal arch effect (see Figure 6).

Figure 6:A Photogarph Illustrating Typical Earthquake Damage (1997 Umbria-Marche earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick masonry, Mortar	0.22 MPa (tension), 4 MPa (compression).	1/3 lime/sand mortar.	18 KN/m^3 (unit weight density).
Foundation				
Frames (beams & columns)				
Roof and floor(s)	Wooden beams.	50 MPa (tension-beams) 30 MPa (compression-beams).		1.5 kN/m^2 (floor weight).

6.2 Builder

Buildings of this type were usually inhabited by the poor and middle class population, and they were built by local craftsmen for the residential purpose only.

6.3 Construction Process, Problems and Phasing

The construction process was generally influenced by the owner's attempt to do the construction at the minimum cost. In the urban layout, an empty space between two existing buildings offered an opportunity to build a new house using the two existing side walls; only the front and rear walls would need to be built. The construction tools were simple (trowel, etc.). The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. In some cases one storey has been added as a part of the refurbishment.

6.4 Design and Construction Expertise

The construction was based on the mason's experience. For this reason , the structural elements were generally oversized in order to achieve high safety. Engineers and architect did not have any role in the design and construction, because the construction process was entirely carried out by masons and/or owners themselves.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma (in Italian). Note that this standard addresses only repair and strengthening of existing buildings, and not the new construction. The year the first code/standard addressing this type of construction issued was 1981. The first code was issued after the 1981 Campania earthquake. Decretory Ministerial 2-7-1981: Normative per le reparation ed il rafforzamento degli edifici dannegiati dal sisma. (Revised in 1986 and 1996). New brick masonry structures are addressed in a different standard. The most recent code/standard addressing this construction type issued was 1996. Title of the code or standard: Normativa per le riparazioni ed il rafforzamento degli edifici dannegiati dal sisma (in Italian). Note that this standard addresses only repair and strengthening of existing buildings, and not the new construction. Year the first code/standard addressing this type of construction issued: 1981 National building code, material codes and seismic codes/standards: The first code was issued after the 1981 Campania earthquake. Decretory Ministerial 2-7-1981: Normative per le reparation ed il rafforzamento degli edifici dannegiati dal sisma. (Revised in 1986 and 1996). New brick masonry structures are addressed in a different standard. When was the most recent code/standard addressing this construction type issued? 1996.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and not authorized as per development control rules.

At present all these constructions are registered and subjected to national/urban codes, which was not the case at the time of their original construction. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s).

6.8 Construction Economics

Unit construction cost cannot be expressed for this type of historic building, because its construction technique and process are no longer practiced. When built up today, these building types are usually constructed with concrete slabs in place of wooden roofs and floors, and very often lintel and staircase are made of reinforced concrete too. In these case the cost unit construction cost can range between 1,000 EURO and 2,000 EURO/m², but it greatly depends upon the quality of materials used. Around 20 days per building.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Roof/floors	Reinforced concrete overlay; the effectiveness of strengthening depends on the roof -to-wall connections.
Roof/floors-Lack of Integrity	Installation of new RC ring beam at the roof level. A procedure for the installation of a RC ring beam is presented in Figure 7B. Figure 7C shows a building strengthened with new RC ring beam at the roof level. It is very important to achieve the connection between the new RC ring beam and the existing masonry, otherwise the earthquake damage may be caused.
Wall-Floor Connection	Installation of metallic ties. Figures 7D and 7E show two different details of ties with anchor plates at the exterior face of the wall. A building strengthened with the ties (similar to detail shown on Fig. 7E) is shown on Figure 7A. It is very important to accomplish a

	regular distribution of ties - irregular tie distribution may be a cause of earthquake damage.
Inadequate seismic resistance of masonry walls	Shotcreting- strengthening walls with shotcrete jackets. Figure 7F shows a masonry wall with shotcreting applied at both faces. The strengthening consists of installing new steel wire mesh and attaching it to the existing wall with through-wall ties or strips spaced at 500 mm on centre both horizontally and vertically. In case shotcreting is not properly applied, the wall can experience earthquake damage as illustrated in Figure 7G.
Inadequate seismic resistance of masonry walls	Stitching and grouting - consists of drilling holes through the walls and installing steel bars; subsequently, the holes are grouted with cement grout, as illustrated in Figure 7H. A building strengthened using this technique is shown on Figure 7I.

Typical seismic repair costs are summarized in Figure 7J.

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?

Yes, to various extent depending on location and buildings.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
In Offida mainly as repair following earthquake damage, but it is expected that some mitigation work should be implemented in conjunction with other architectural or functional alterations to existing unstrengthened buildings.

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

Project plans need to be presented to local authority, but it is expected that there is no formal site inspection.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

An engineer is usually involved, but work might be carried out either by a contractor or by the user.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The performance varies highly depending on the quality of construction. Buildings retrofitted with anchors, which are less sensitive to workmanship usually perform well in preventing the out-of plane failures. Ring beams and other strengthening with concrete structures tends to substantially alter the stiffness ratio of wall-to-floor structures and if not implemented properly can cause serious damage to load-bearing walls.

Figure 7A: Illustration of Seismic Strengthening Techniques

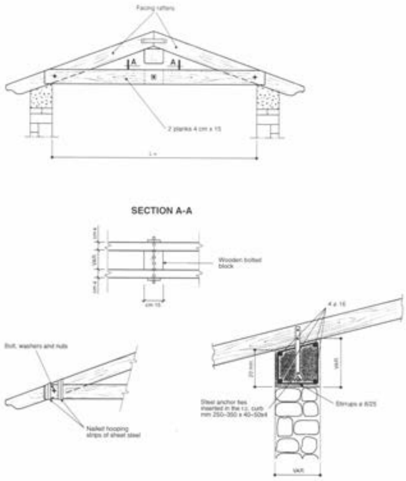


Figure 7B: Seismic Strengthening - Installation of a New RC Ring Beam at the Roof Level

Figure 7C: Seismic Strengthening - Installation of a New RC Ring Beam at the Roof Level (Design Application)

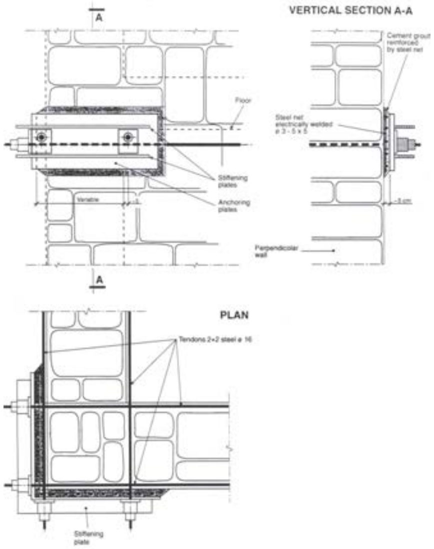


Figure 7D: Seismic Strengthening : Wall-to-Floor Anchorage

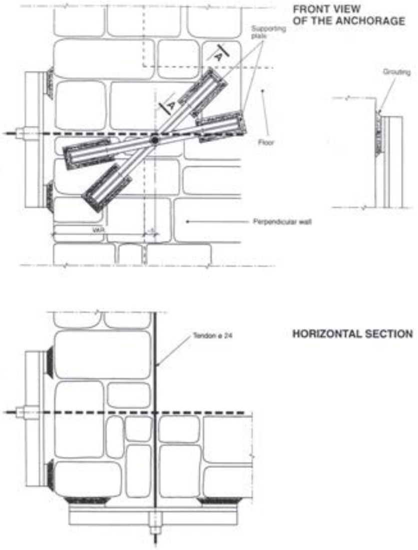


Figure 7E: Seismic Strenghthening - Wall-to-Floor Anchorage

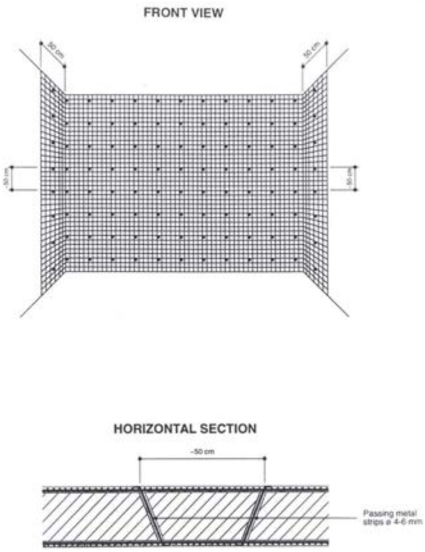


Figure 7F: Seismic Strengthening - Shotcreting

Figure 7G: Seismic Strengthening - Damage of Wall Strengthened by Shotcreting

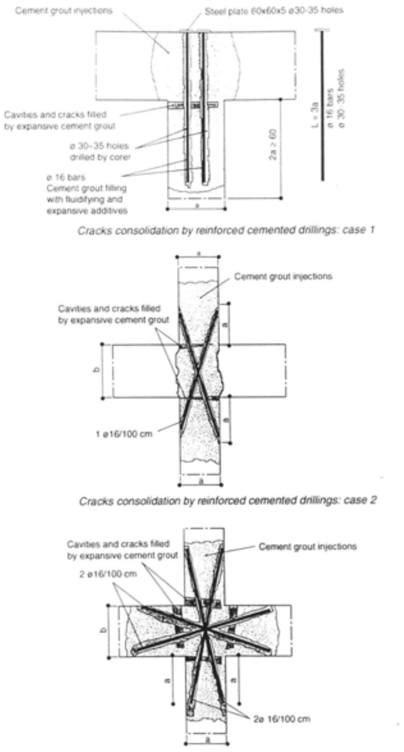
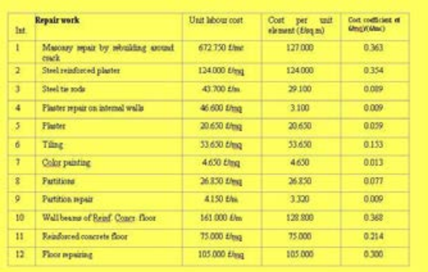


Fig. 2

Figure 7H: Seismic Strengthening - Stitching and Grouting

Figure 7I: Seismic Strengthening - Stitching and Groutng (Design Application)



Int.	Repair work	Unit labour cost	Cost per unit element (£/sq.m)	Cost coefficient at £/mq)/(£/mc)
1	Masonry repair by rebuilding around crack	672 750 £/mc	127 000	0.363
2	Steel reinforced plaster	124 000 £/mq	124 000	0.354
3	Steel tie rods	43 700 £/m	29 100	0.089
4	Plaster repair on internal walls	46 600 £/mq	3 100	0.009
5	Plaster	20 650 £/mq	20 650	0.059
6	Tiling	53 650 £/mq	53 650	0.153
7	Color painting	4 650 £/mq	4 650	0.013
8	Partitions	26 850 £/mq	26 850	0.077
9	Partition repair	4 150 £/m	3 320	0.009
10	Wall beams of Reinf. Concr. floor	161 000 £/m	128 800	0.368
11	Reinforced concrete floor	75 000 £/mq	75 000	0.214
12	Floor repairing	105 000 £/mq	105 000	0.300

Figure 7J: Seismic Strengthening-Costs of Typical Repairs (After SSI, 1999)

Reference(s)

1. Vulnerability of Buildings in historic town centres
   D'Ayala,D., and Spence,R.
   Proceedings of the VII National Conference "L'Ingegneria Sismica in Italia", Siena. pp.363-372 1995

2. Earthquake Loss Estimation for Europe's historic Town Centres
   D'Ayala,D., Spence,R., Oliveira,C., and Pomonis,A.
   Earthquake Spectra Special Issue on Earthquake Loss Estimation, November, pp. 773-793 1997

3. The Umbria-Marche Earthquake of September 1997 - Preliminary Structural Assessment
   Spence,R., and D'Ayala,D.
   The Structural Engineering International, Journal of the IABSE. Vol.9, No.3, pp. 229-233 (also available on line at http://www.iabse.ethz.ch/sei/sei_f.html) 1999

4. Correlation of seismic damage between classes of buildings: churches and houses
   D'Ayala,D.
   Seismic damage to masonry buildings, pp. 41-58. Balkema Press, Rotterdam 1999

5. Identificazione dei Meccanismi di Collasso per la stima della Vulnerabilit
   D'Ayala,D., and Speranza,E.
   Proceedings of the IX National Congress "L'Ingegneria Sismica in Italia", Torino 20-23 settembre 1999

6. Establishing Correlation Between Vulnerability And Damage Survey For Churches
   D'Ayala,D.
   Proceedings of 12th World Conference On Earthquake Engineering, paper 2237/10/a 2000

7. Confronto di misure di vulnerabilit
   D'Ayala,D, and Speranza,E.
   research carried out in collaboration with the GNDT U.R. of Padova (Italy), internal report of Dept. of. "Costruzioni e Trasporti" of University of Padova, (It) 2000

8. Seismic vulnerability of historic centres: the case study of Nocera Umbra, Italy
   D'Ayala,D, and Speranza,E.
   Proceedings of the UNESCO Congress on "More than two thousand years in the history of architecture" 2001

9. A procedure for evaluating the seismic vulnerability of historic buildings at urban scale based on mechanical parameters
   D'Ayala,D, and Speranza,E.
   Proceedings of the 2nd International Congress "Studies in Ancient Structures, Yildiz, Instanbul Turkey, July 2001

10. Unreinforced Brick-Block Masonry - Traditional Housing in Central Italy
   D'Ayala,D., and Speranza,E.
   Workshop on the EERI/IAEE Housing Encyclopedia Project, Pavia, Italy (also available online at www.world-housing.net) 2001

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